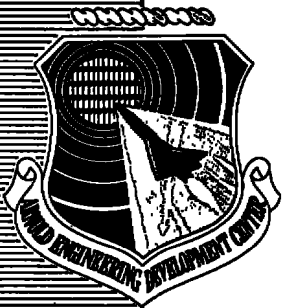


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**FLUTTER TEST OF A 0.50-SCALE
MOL METEOROID SHIELD PANEL
AT MACH NUMBERS FROM 1.2 TO 2.5**

C. D. Riddle

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FOREWORD

The work reported herein was done at the request of the Space Systems Division (SSD), Air Force Systems Command (AFSC), for the Missile and Space Systems Division of the McDonnell-Douglas Corporation under Program Element 35121F, Program Area 632A.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The test was conducted under ARO Project No. PT0767 from October 31 to December 11, 1968. The manuscript was submitted for publication on January 20, 1969.

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This technical report has been reviewed and is approved.

Richard W. Bradley
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Director of Test

ABSTRACT

A 0.50-scale model of the meteoroid shield portion of the MOL laboratory vehicle was tested in Tunnels 16T and 16S of the Propulsion Wind Tunnel Facility. The model consisted of a sting-supported hollow duct assembly about which the dynamically scaled meteoroid shield skin and various protuberances were mounted. The test objective was to determine if the shield was free of destructive flutter in the flight dynamic pressure environment. Principal shield data included measurements of strain, displacement, temperature, noise level, surface pressure, and boundary-layer profile. Data were recorded at nominal Mach numbers from 1.25 to 1.50 in Tunnel 16T and from 1.70 to 2.25 in Tunnel 16S. Dynamic pressure was varied from tunnel minimums to levels that exceeded the scaled flight value. No indications of flutter were observed.

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NOMENCLATURE

C_p	Pressure coefficient, $\frac{p_\ell - p_\infty}{q_\infty}$
M_L	Local Mach number computed from boundary-layer rake measurements
M_{L_A}	Local Mach number corresponding to the outermost probe of rake A
M_∞	Free-stream Mach number
p_ℓ	Static pressure measured on the model surface, psf
q_L	Local dynamic pressure computed from boundary-layer rake measurements, psf
q_{L_A}	Local dynamic pressure corresponding to the outermost probe of rake A, psf
q_∞	Free-stream dynamic pressure, psf
Re/ft	Reynolds number per foot, V_∞/ν_∞
V_∞	Free-stream velocity, ft/sec
y	Rake probe distance from the model surface, in.
α	Angle of attack relative to the tunnel centerline, deg
ν_∞	Kinematic viscosity of the free stream, ft^2/sec
ϕ	Angle of roll relative to the inlet centerline, deg
ψ	Angle of yaw relative to the tunnel centerline, deg

SECTION I INTRODUCTION

A 0.50-scale model of the meteoroid shield portion of the MOL laboratory vehicle was tested in the Propulsion Wind Tunnels, Supersonic (16S) and Transonic (16T) of the Propulsion Wind Tunnel Facility (PWT). The model consisted of a sting-supported open inlet core structure circumscribed by a dynamically scaled shield skin upon which various protuberances were mounted. The inlet was designed to alleviate tunnel blockage.

The purpose of the investigation was to determine if the shield was free of destructive flutter in the flight dynamic pressure environment. Data were recorded at nominal discrete Mach numbers of 1.25, 1.40, and 1.50 in Tunnel 16T and 1.70, 2.00, and 2.25 in Tunnel 16S.

SECTION II APPARATUS

2.1 TEST FACILITY

Tunnel 16T is a variable density wind tunnel capable of operation from Mach numbers 0.55 to 1.60. The test section is 16 ft square in cross section and is lined with perforated plates to allow continuous operation with minimum wall interference.

Tunnel 16S is also a variable density wind tunnel with a 16-ft square test section and is capable of operation at Mach numbers from 1.60 to 4.75.

Test section details showing model location and support strut arrangement are presented in Fig. 1, Appendix I. A more extensive description of each tunnel is given in the Test Facilities Handbook.¹

2.2 MODEL DESCRIPTION

The 0.50-scale MOL panel flutter model consisted of a sting-supported rigid hollow duct assembly circumscribed by

¹Test Facilities Handbook (Seventh Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, July 1968.

a dynamically scaled meteoroid shield skin and various protuberances. The hollow duct was designed to alleviate tunnel blockage. The model is sketched and detailed in Fig. 2a. Pertinent scaling ratios are listed in Table I. A comparison of Fig. 2a with protuberance photographs in Fig. 2b illustrates the shape and relative sizes of the protuberances.

The shield was constructed of 0.008-in.-thick magnesium and consisted of four panels with radial dimensions of 40, 50, 135 and 135 deg. The forward edge of the shield was faired to the core by a 20-deg ramp as depicted in Figs. 2a and c. The skin surface geometry consisted of longitudinal corrugations referred to as beads. The beads are shown in the photograph of Fig. 2c and are sketched in Fig. 2d. The typical inside section of skin shown in Fig. 2e pictures a portion of the 18 circumferential ring frame supports arrayed longitudinally along the skin. The ring spacing and orientation to bead geometry are shown in Fig. 2d.

The cavity between the skin and core was vented through several small-diameter holes in the skin. The venting helped reduce static pressure differential loads across the shield.

2.3 INSTRUMENTATION

The skin and core were instrumented for measurement of strain, displacement, temperature, noise level, surface pressure, boundary-layer profile, and acceleration. The quantity and location of each type of measurement are shown in Fig. 3. The boundary-layer rakes are detailed in Fig. 4.

Outputs from the strain gages, displacement sensors, microphones, and accelerometers were FM-recorded on magnetic tape for subsequent data analysis. The temperature, surface pressure, and boundary-layer measurements were channelled through analog-to-digital converters for computer reduction and on-line tabulation.

SECTION III TEST DESCRIPTION

3.1 PROCEDURE

Data were recorded at nominal discrete Mach numbers of 1.25, 1.40, and 1.50 in Tunnel 16T and 1.70, 2.00, and 2.25

in Tunnel 16S. For a typical flutter test run, Mach number was set at the minimum tunnel dynamic pressure level. Dynamic pressure, q , was then varied from tunnel minimum to a level in excess of the scaled flight value, then lowered back to tunnel minimum. Dynamic data were tape-recorded continuously during the q sweep, whereas the steady-state data were acquired at pauses during the q increase only. Separate pressure sweeps for model pitch-yaw combinations of 0, 0 deg; -4, 0 deg; and 0, -4 deg were obtained for each of the six nominal Mach numbers. Figure 5 compares a map of the q sweep range for a model pitch-yaw attitude of 0, 0 deg with the scaled flight q values as a function of Mach number. A tabulation of pertinent test conditions recorded during each q sweep is given in Table II. Local Mach number and dynamic pressure listed in Table II were measured at station 32.3 on the skin and corresponded to the outermost probe of rake A. The rake A location was selected to correspond with that of rake data measured during a previous investigation.²

In compliance with test requirements, a 1.0-in.-wide aluminum strap was bolted about the downstream edge of the flutter panel for a portion of the Tunnel 16S testing. The associated discrete conditions are identified as "fixed-end" data in Table I.

In an effort to limit the time of exposure of the skin to high q levels, the pressure sweeps were conducted as rapidly as possible. The variations in free-stream Mach number shown in Table II for Tunnel 16T q sweeps resulted from a difficulty in maintaining correct tunnel pressure ratio during the rapid q increases. The Mach numbers set for Tunnel 16S are primarily dependent on nozzle contour and were therefore less variant during q sweeps.

Table II also shows that for both tunnels the reference local Mach number, M_{LA} , generally tended to increase relative to the free-stream Mach number as dynamic pressure was raised. The M_{LA} increase was apparently caused by an indicated decrease in the rake A static reference pressure relative to free-stream static pressure.

Before q sweeps were begun in each tunnel, Mach number surveys were conducted at low q levels to obtain a correlation

²R. W. Butler and J. F. Riddell. "Steady and Fluctuating Pressures Around Flow Protuberances on the MOL Vehicle at Transonic Speeds." AEDC-TR-68-203 (AD840127L), September 1968.

between free-stream tunnel condition measurements and conditions measured locally by rake A. A further consideration during the Mach number sweeps in Tunnel 16T was to confirm that the inlet was started at all test conditions of interest. The starting Mach number for the inlet was approximately 1.2.

3.2 PRECISION OF MEASUREMENTS

The estimated precision of measurements for dynamic pressure and model attitude are as follow:

Angle of attack or yaw: ± 0.10 deg

Dynamic pressure: $M_\infty < 1.40$, ± 4 psf

$M_\infty > 1.40$, ± 3 psf

The variations of Mach number along the centerline of blockage-free test sections in Tunnels 16T and 16S are estimated to be as follow:

Mach number: 1.20 to 1.55, ± 0.010

1.70 to 2.25, ± 0.020

The uncertainties in plotted data are estimated to be as follow:

$$\Delta C_p = \pm 0.02$$

$$\Delta M_L = \pm 0.04$$

SECTION IV RESULTS

Boundary-layer profiles and surface pressure distributions are presented in Figs. 6 and 7, respectively. Figure 6 shows variations of rake local Mach number, M_L , with distance from the surface, y , at several q levels for each nominal Mach number. Angles of attack, α , and yaw, ψ , were set at 0 deg for the Fig. 6 data. Rakes B and C were located on the core just upstream of the ramp and rake A was located on the shield (see Fig. 4). Rake B was oriented radially behind an Attitude Control Translation System (ACTS) module (see Fig. 2a) and tended to show lower Mach numbers than did rake C, which was radially located between ACTS modules.

Figure 6c trends of M_L at nominal Mach number 1.50 correspond to the only ACTS modules-removed condition for which rake data are presented. Rake B and C magnitudes of M_L are uniquely similar in Fig. 6c, indicating the module effect on the rake B data.

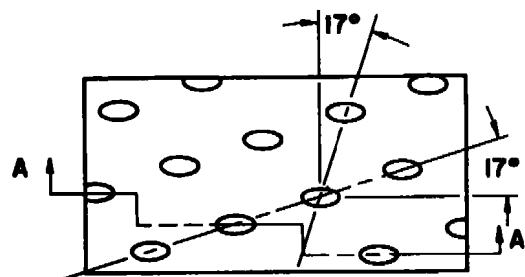
Longitudinal variations of surface pressure coefficient, C_p , are compared for nominal radial locations of 0, 44, and 316 deg at $\alpha, \psi = 0$ deg in Fig. 7. Data for each Mach number were recorded at the peak q value obtained during a pressure sweep. The Mach number 1.55 data correspond to a test condition with the ACTS modules removed. The dashed portions of the faired curves represent estimated C_p behavior in the vicinity of the 20-deg ramp. At model station 18.4, the 0-deg-ray orifice exhibited more positive values of C_p at all Mach numbers than did the orifices on the 44- and 316-deg rays. A more negative value of C_p is shown for the 0-deg-ray orifice at model station 42.9 for Mach numbers 1.28 through 1.70. The observed differences are probably associated with effects of local skin geometry. As noted in Fig. 3, the 0-deg-ray orifices were located on a smooth lap joint, whereas skin orifices along the 44- and 316-deg rays were positioned between fore and aft beads. Figure 3 also shows the 0-deg-ray orifice at model station 18.4 to be positioned just forward of the helix antenna protuberance, a location which could result in the higher values of C_p noted in Fig. 7.

In Tunnel 16T, flow separation downstream of the ACTS modules apparently induced severe buffet loads locally on the skin near the ramp, as evidenced by the damage pictured in Fig. 2c. After the damage incident, the ACTS modules were removed for the remainder of the Tunnel 16T entry to alleviate the buffet loads. The ACTS modules were installed throughout the 16S test.

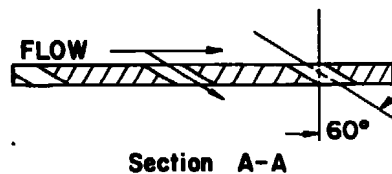
APPENDIXES

I. ILLUSTRATIONS

II. TABLES

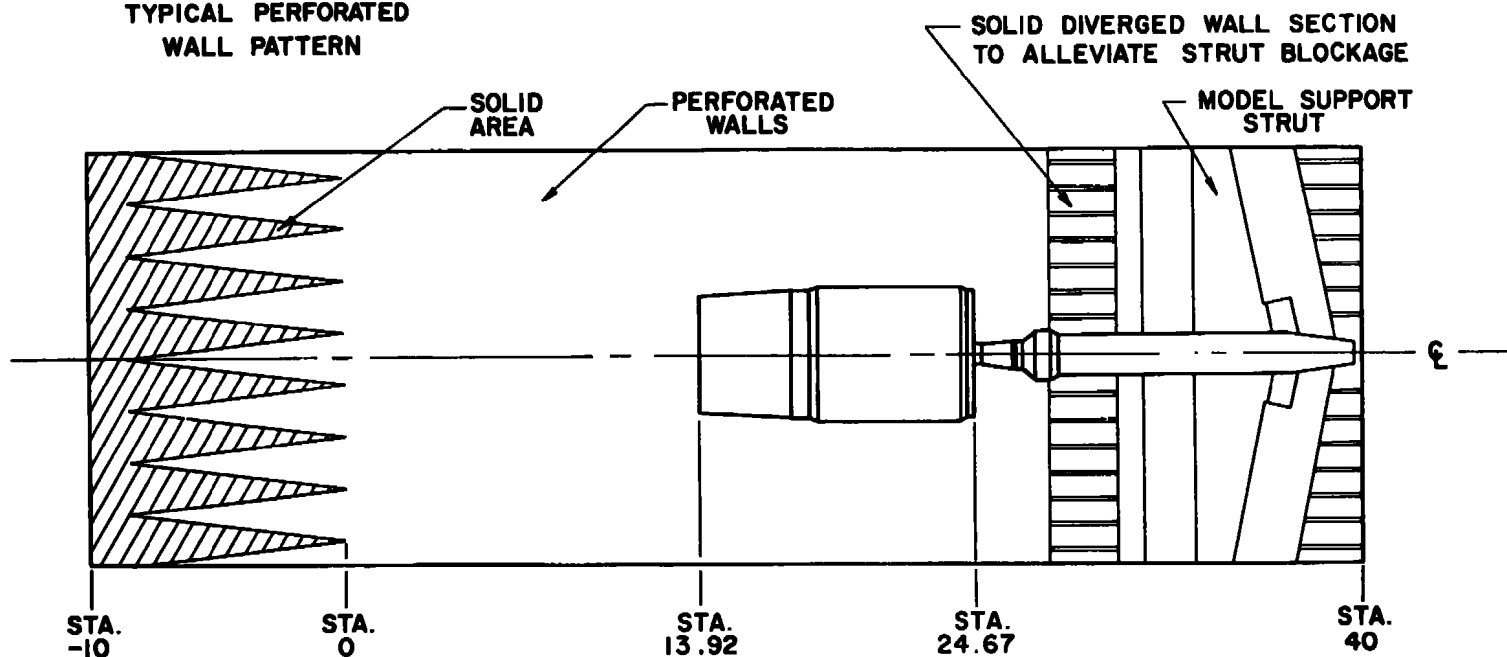


TYPICAL PERFORATED
WALL PATTERN



TUNNEL STATIONS IN FEET

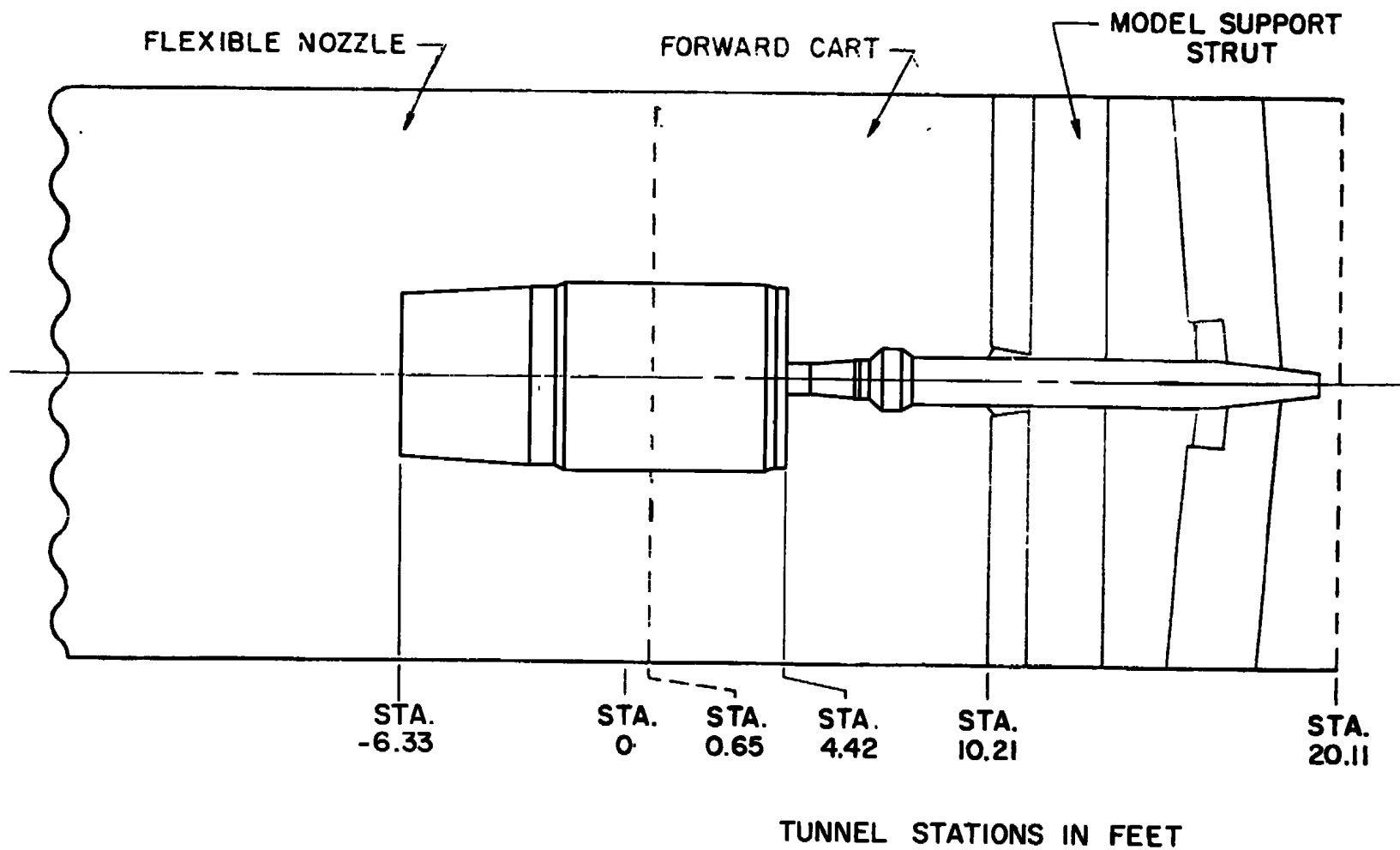
6% Open Area
Hole Diameter = 0.75 In.
Plate Thickness = 0.75 In.



a. Sketch of the 16 T Installation

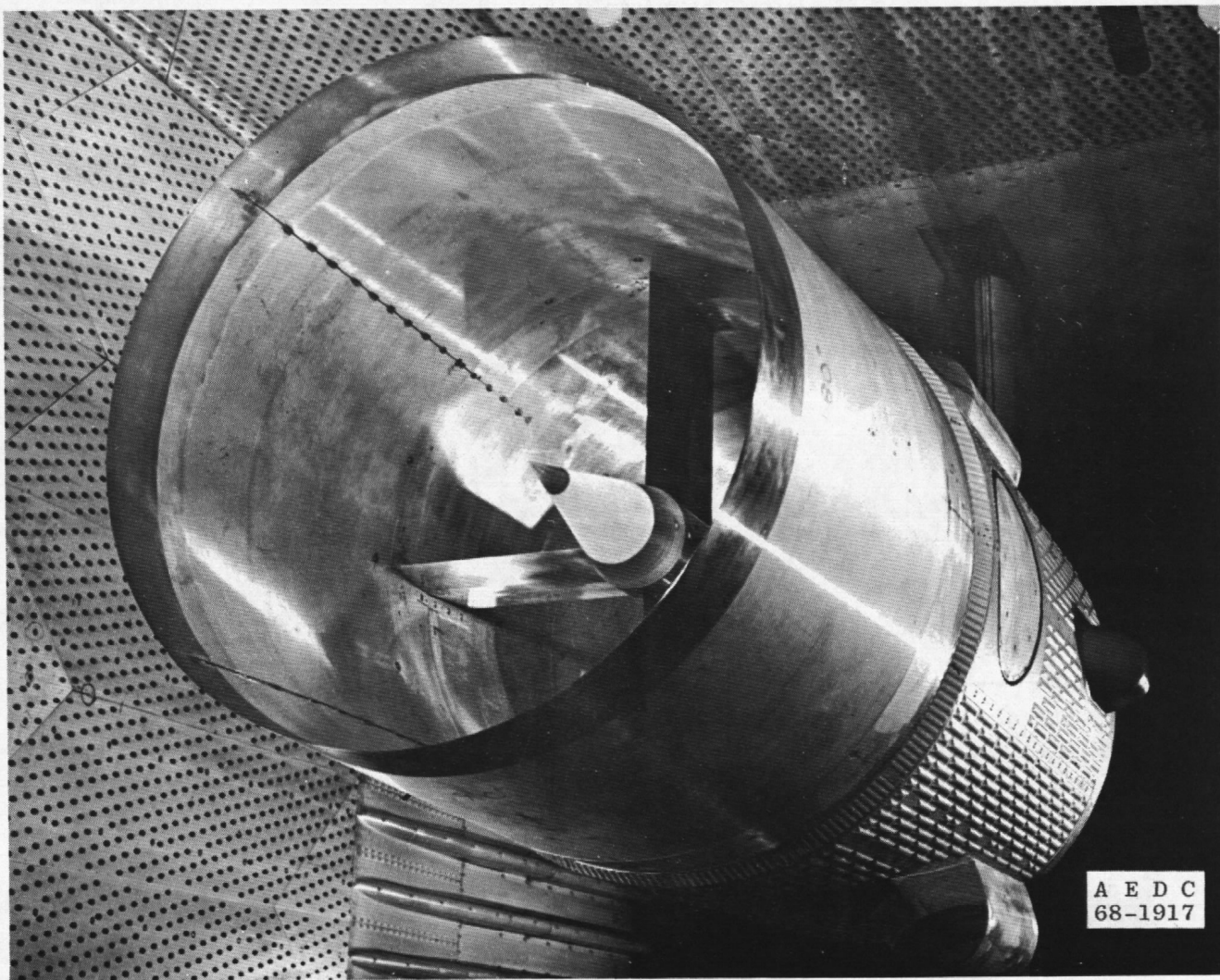
Fig. 1 Installation of the MOL Meteoroid Shield Flutter Model in Tunnels 16T and 16S

10



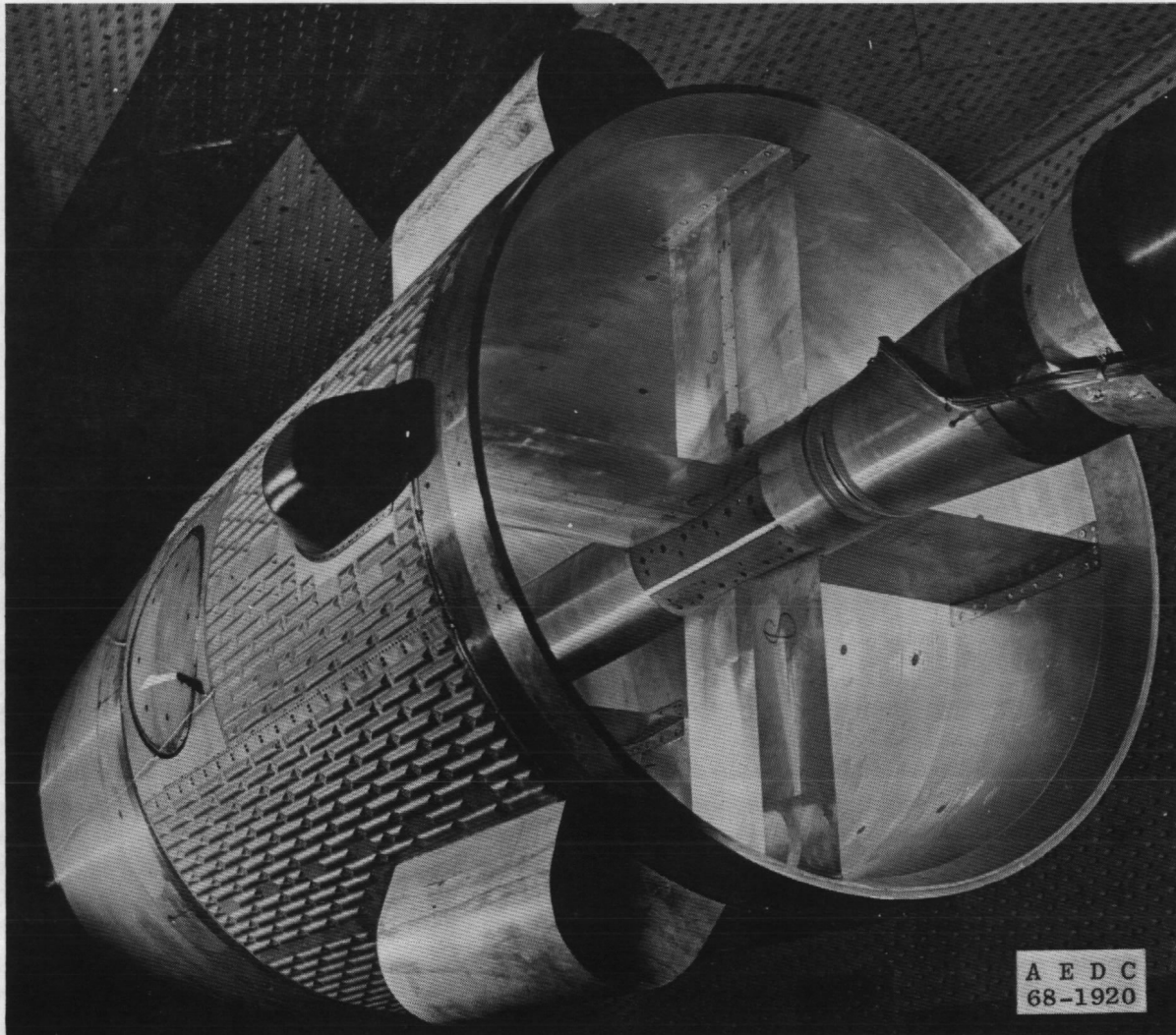
b. Sketch of the 16S Installation

Fig. 1 Continued



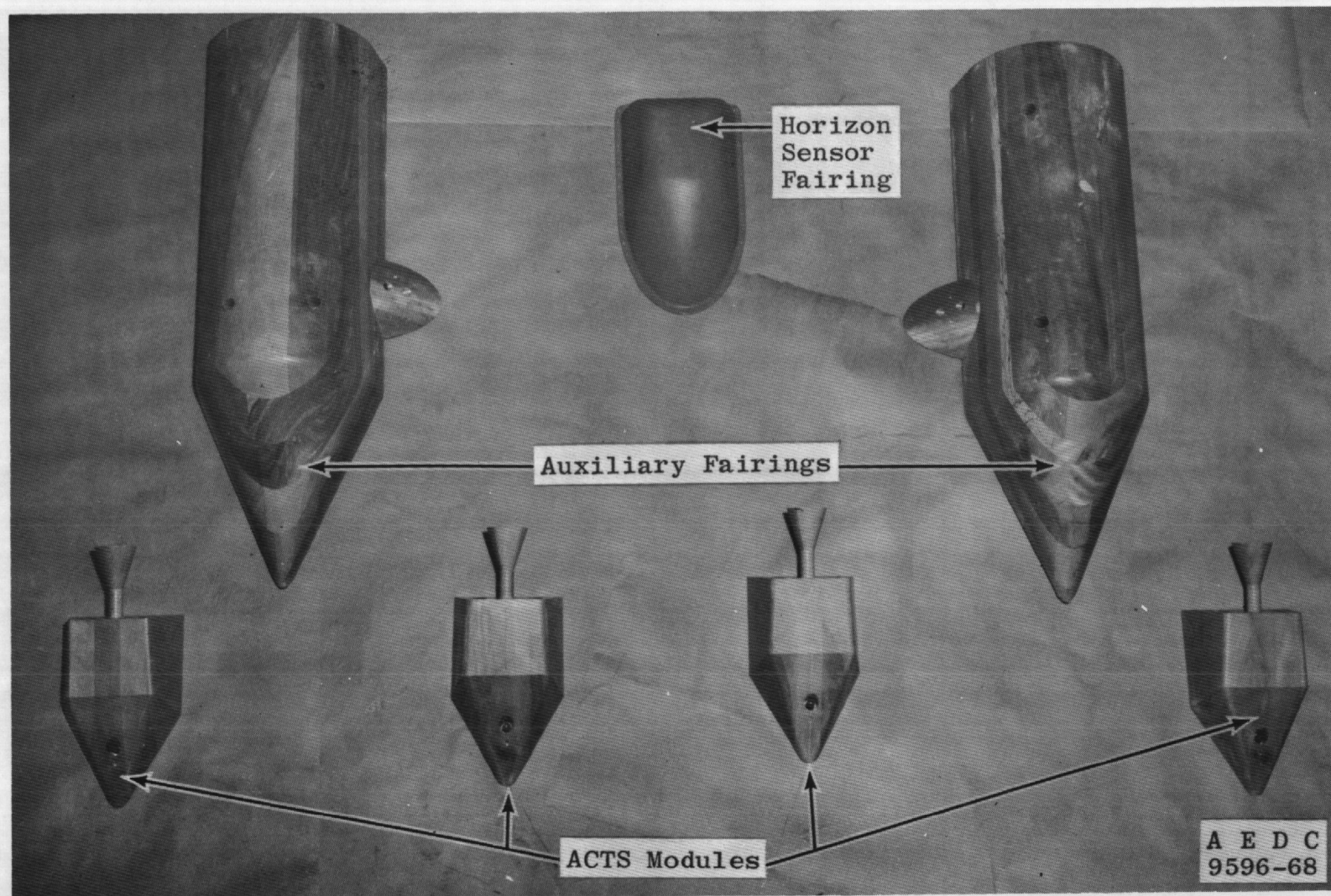
c. Photograph of the 16T Installation as Viewed from Upstream, $\phi = 90$ deg

Fig. 1 Continued



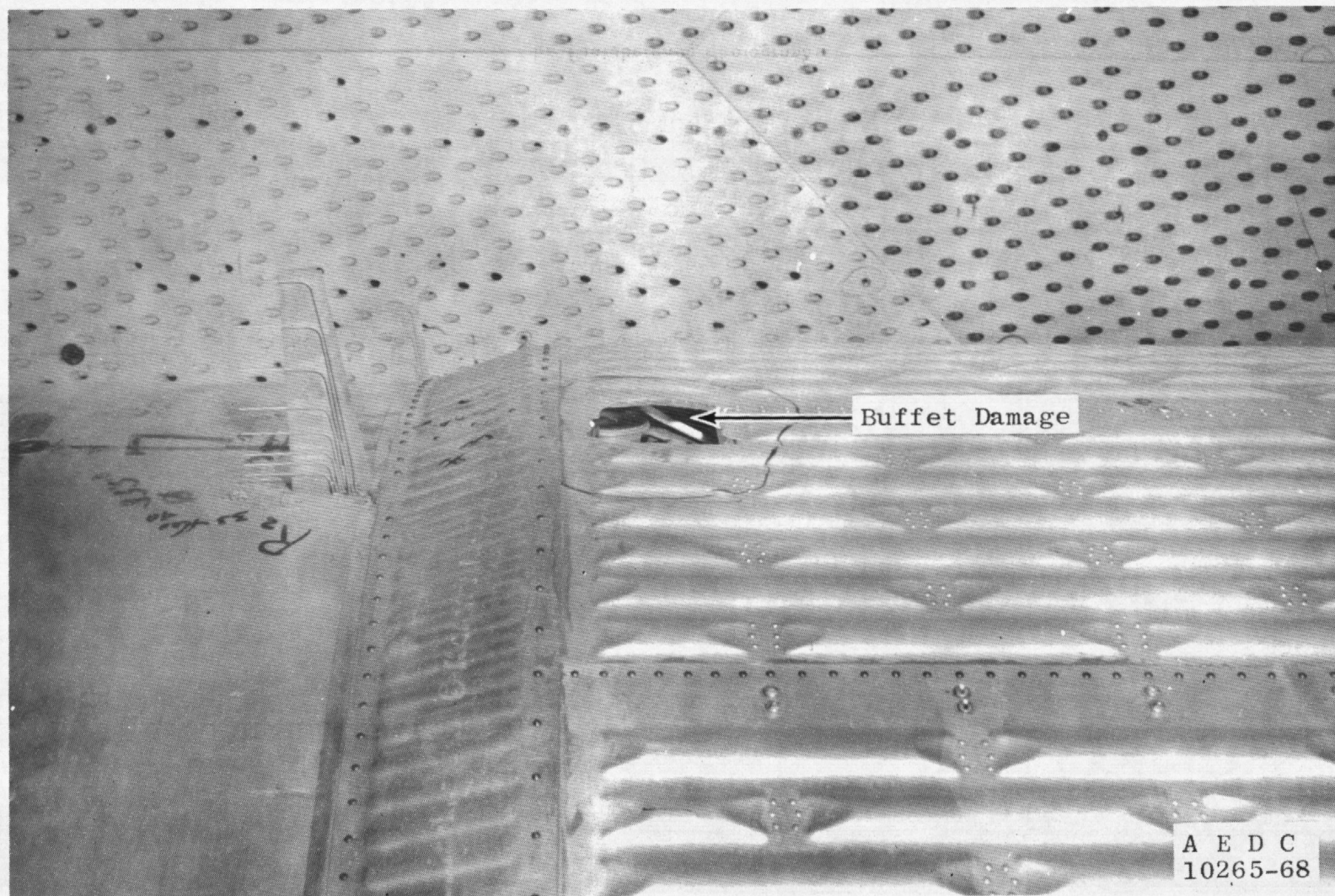
d. Photograph of the 16T Installation as Viewed from Downstream, $\phi = 90$ deg
Fig. 1 Concluded

a. Composite Sketch
Fig. 2 Model Geometry

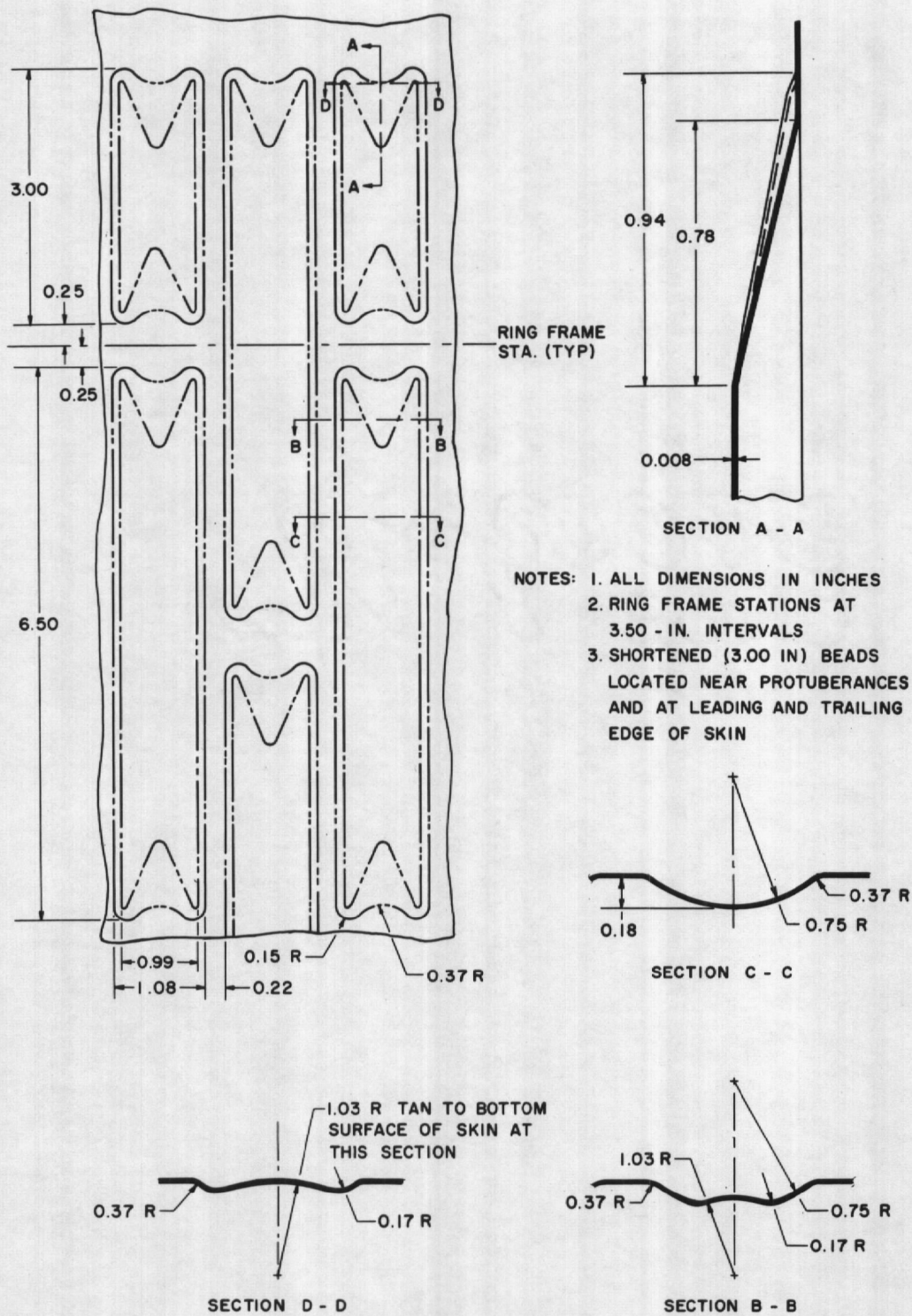


b. Protuberance Photographs

Fig. 2 Continued



c. Photograph Showing Rake, Ramp, and Bead Geometry
Fig. 2 Continued



d. Sketch of Bead Geometry

Fig. 2 Continued



e. Photograph Showing Panel Ring Frame Supports
Fig. 2 Concluded

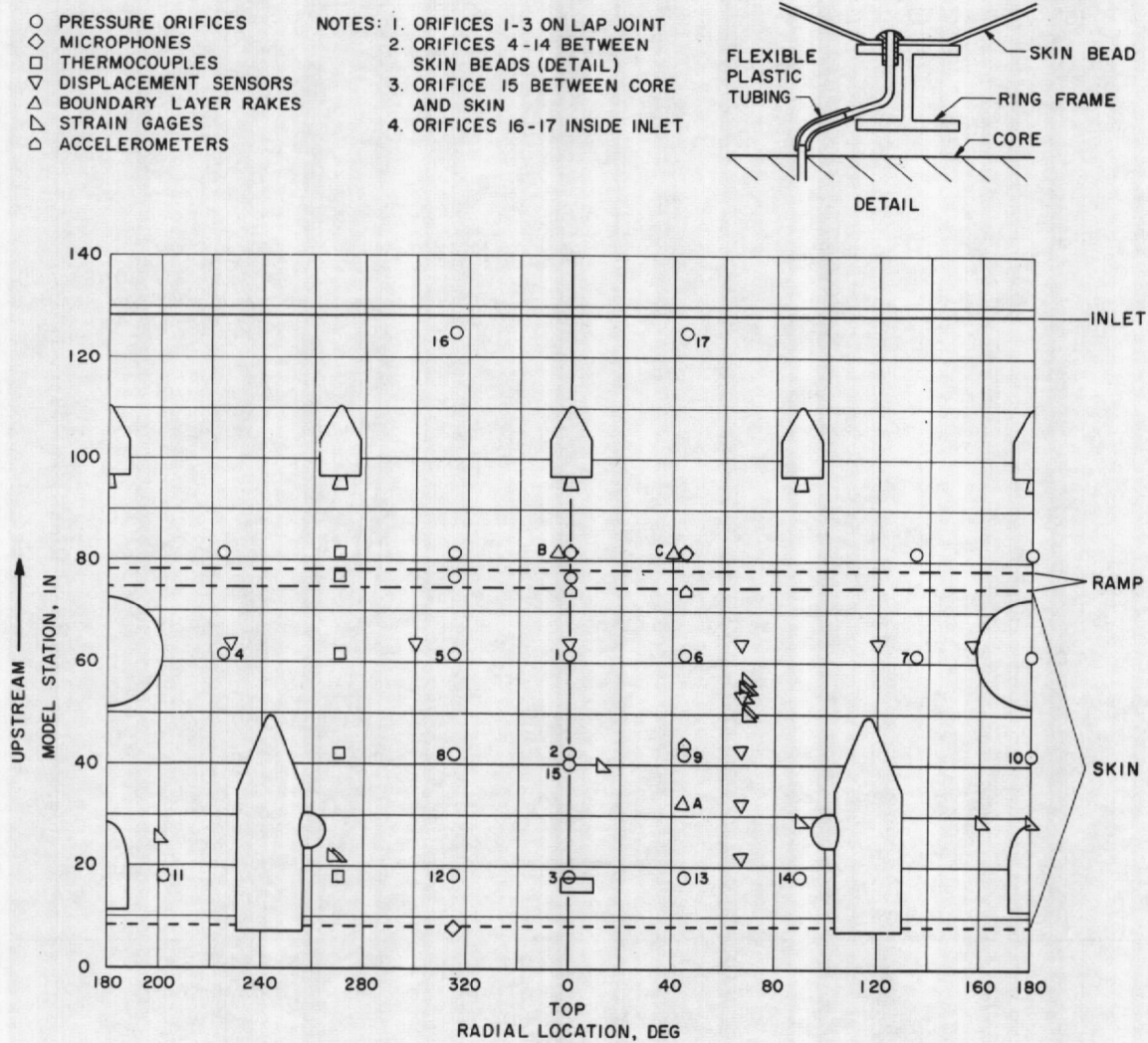


Fig. 3 Instrumentation Composite

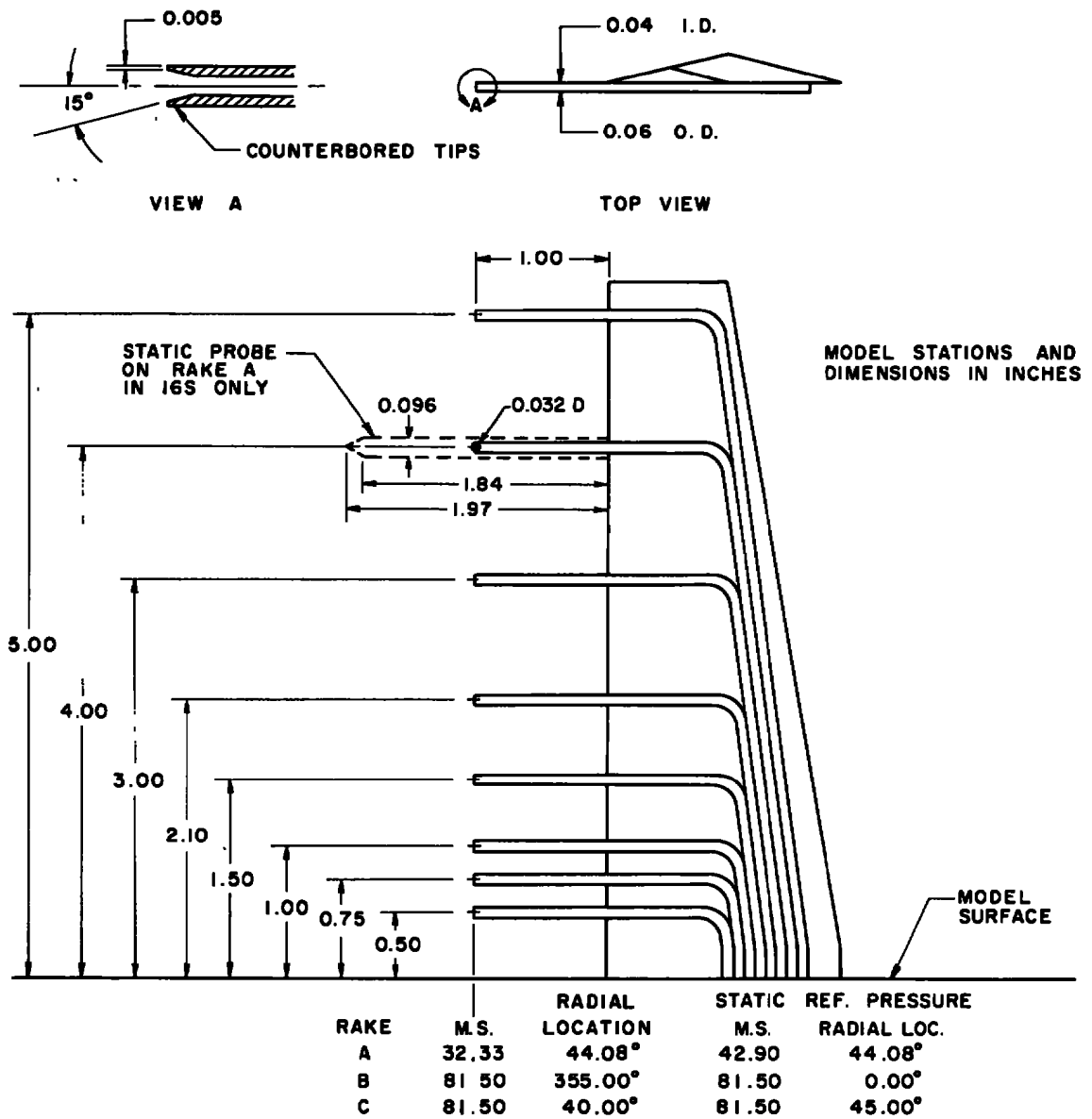


Fig. 4 Rake Details

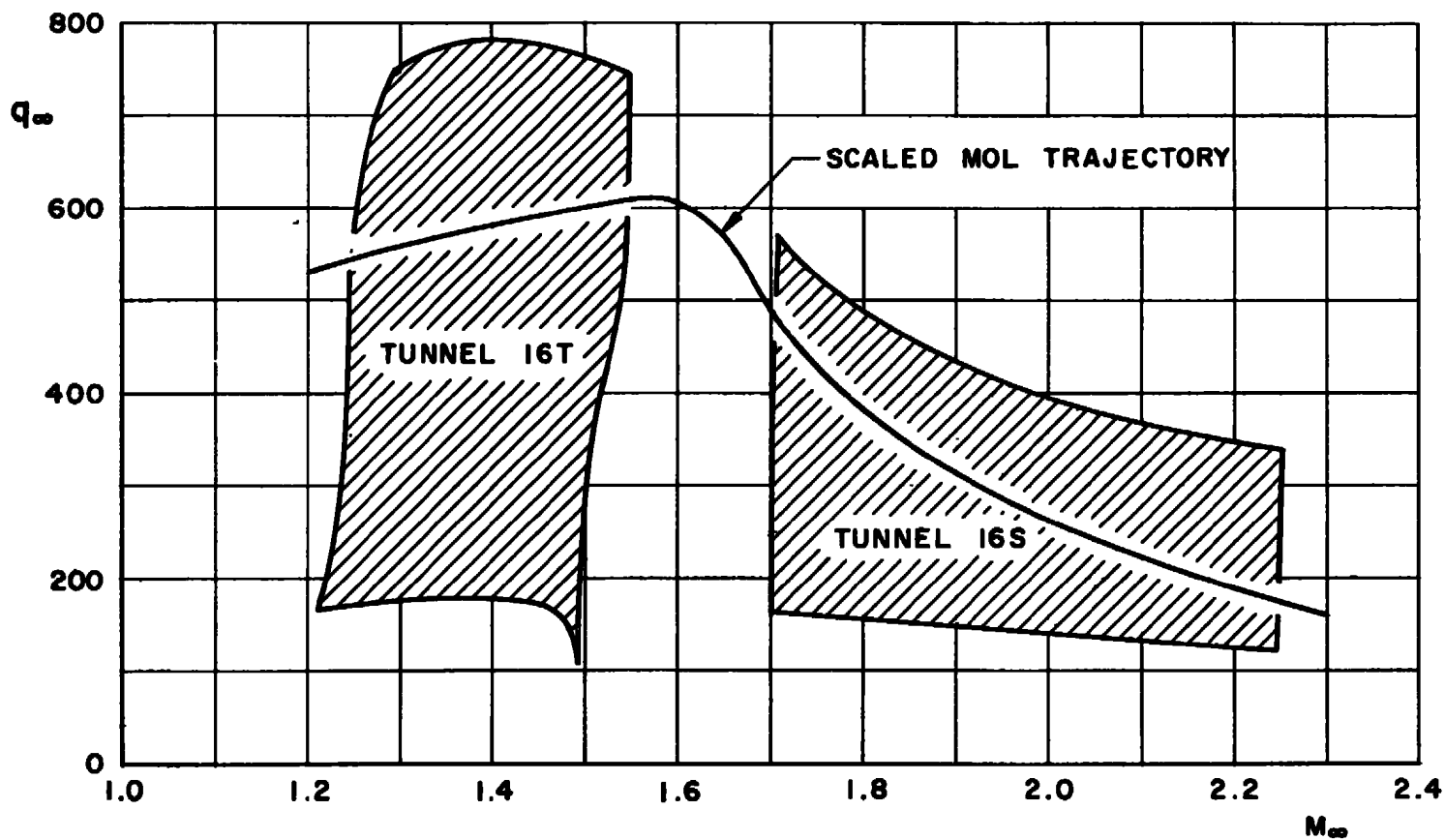
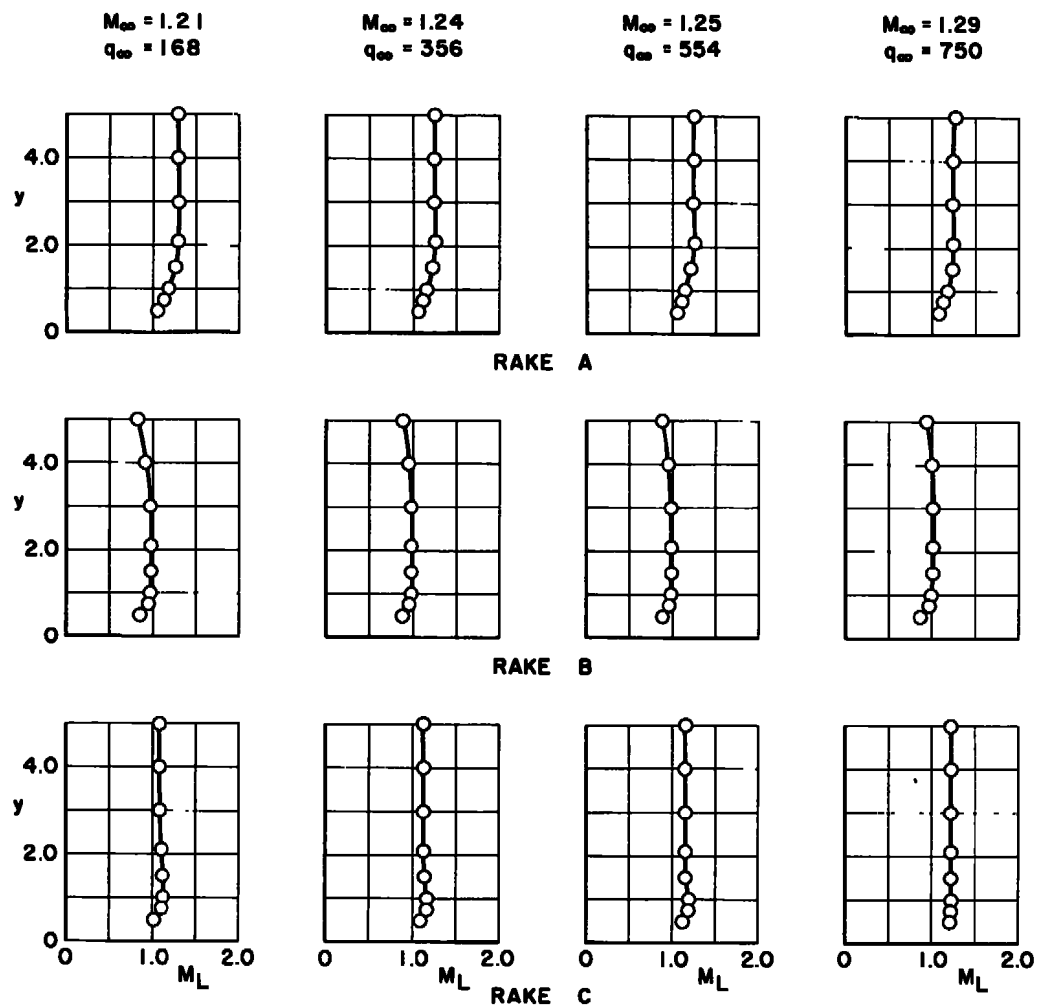
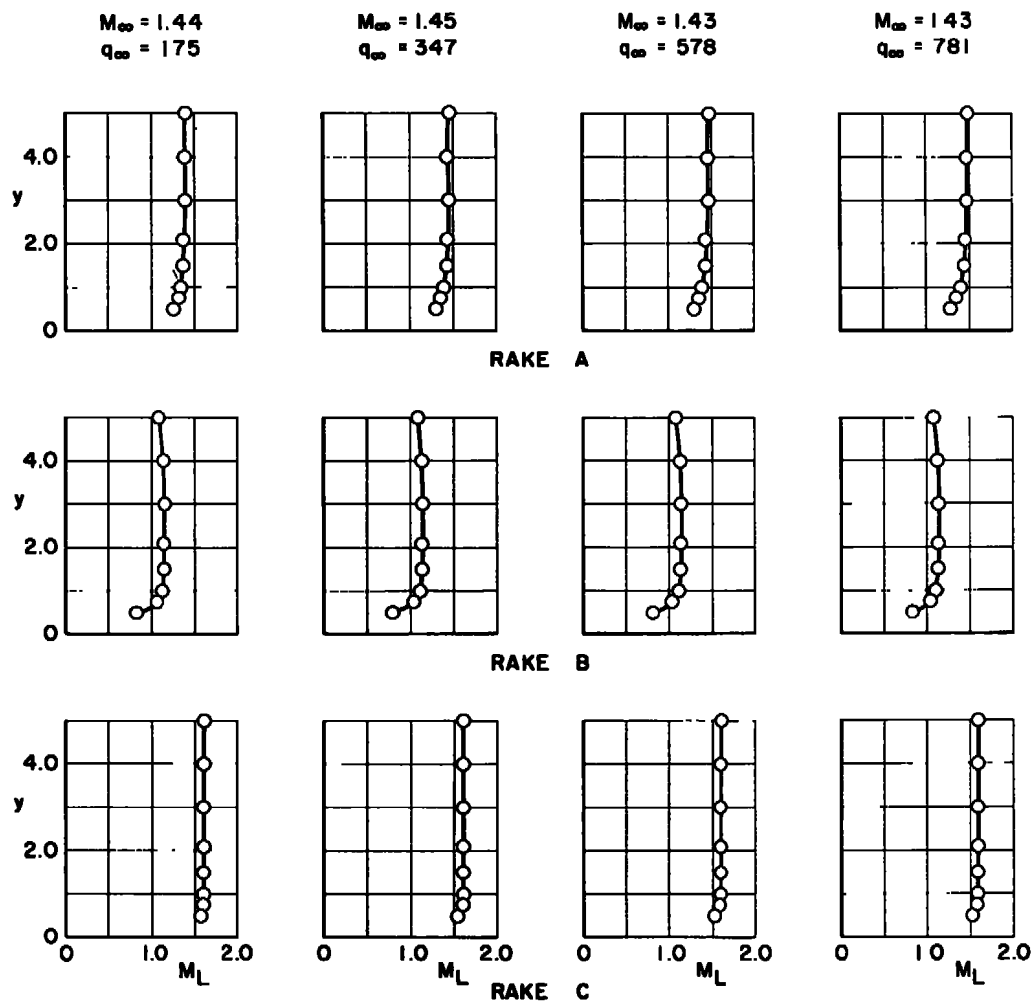


Fig. 5 Variation of Dynamic Pressure with Mach Number Comparing the Scaled Flight Curve with the Tunnel Test Range for $\alpha, \psi = 0$ deg

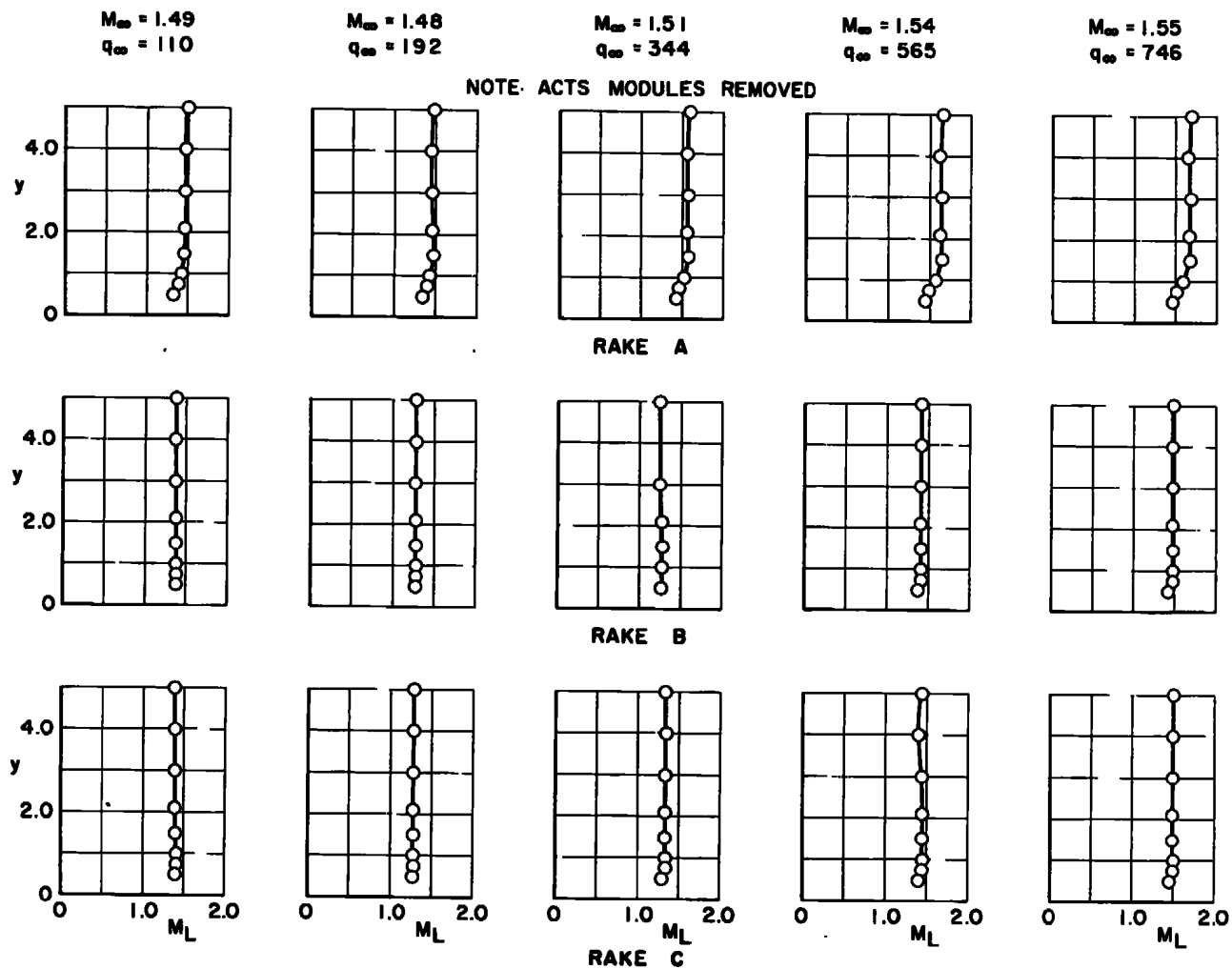


a. Nominal Mach Number 1.25

Fig. 6 Local Mach Number Profiles for $\alpha, \psi = 0$ deg

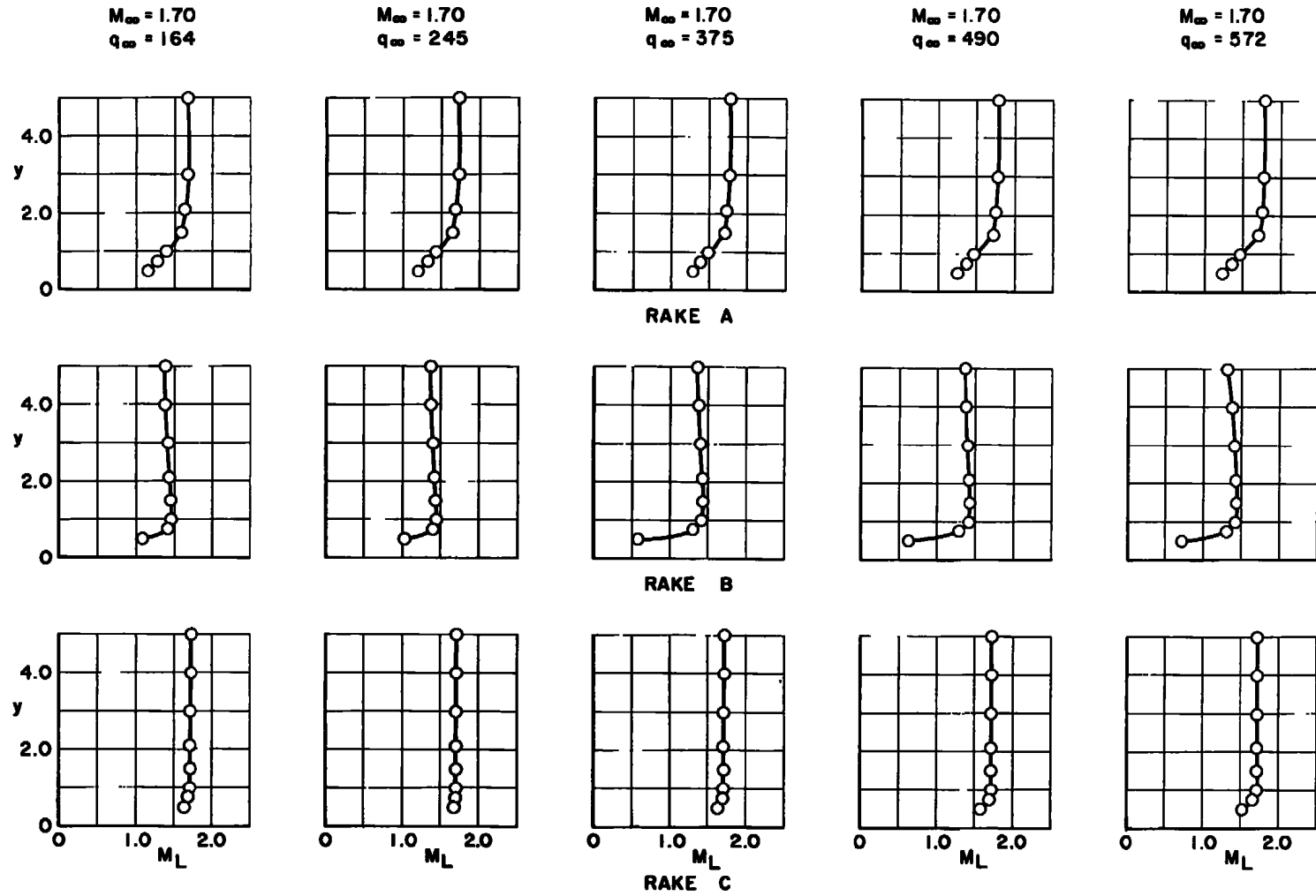


b. Nominal Mach Number 1.40
 Fig. 6 Continued

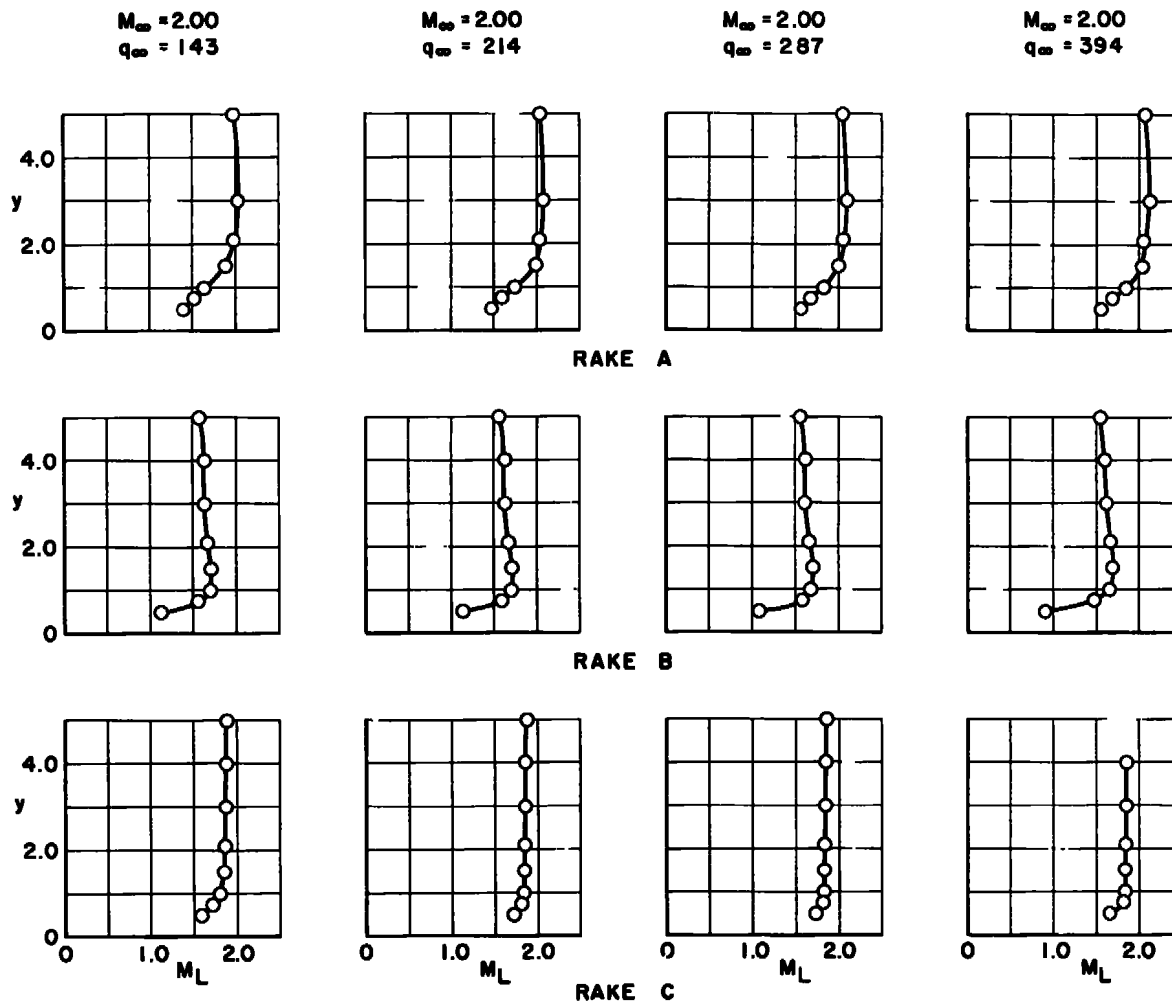


c. Nominal Mach Number 1.50

Fig. 6 Continued

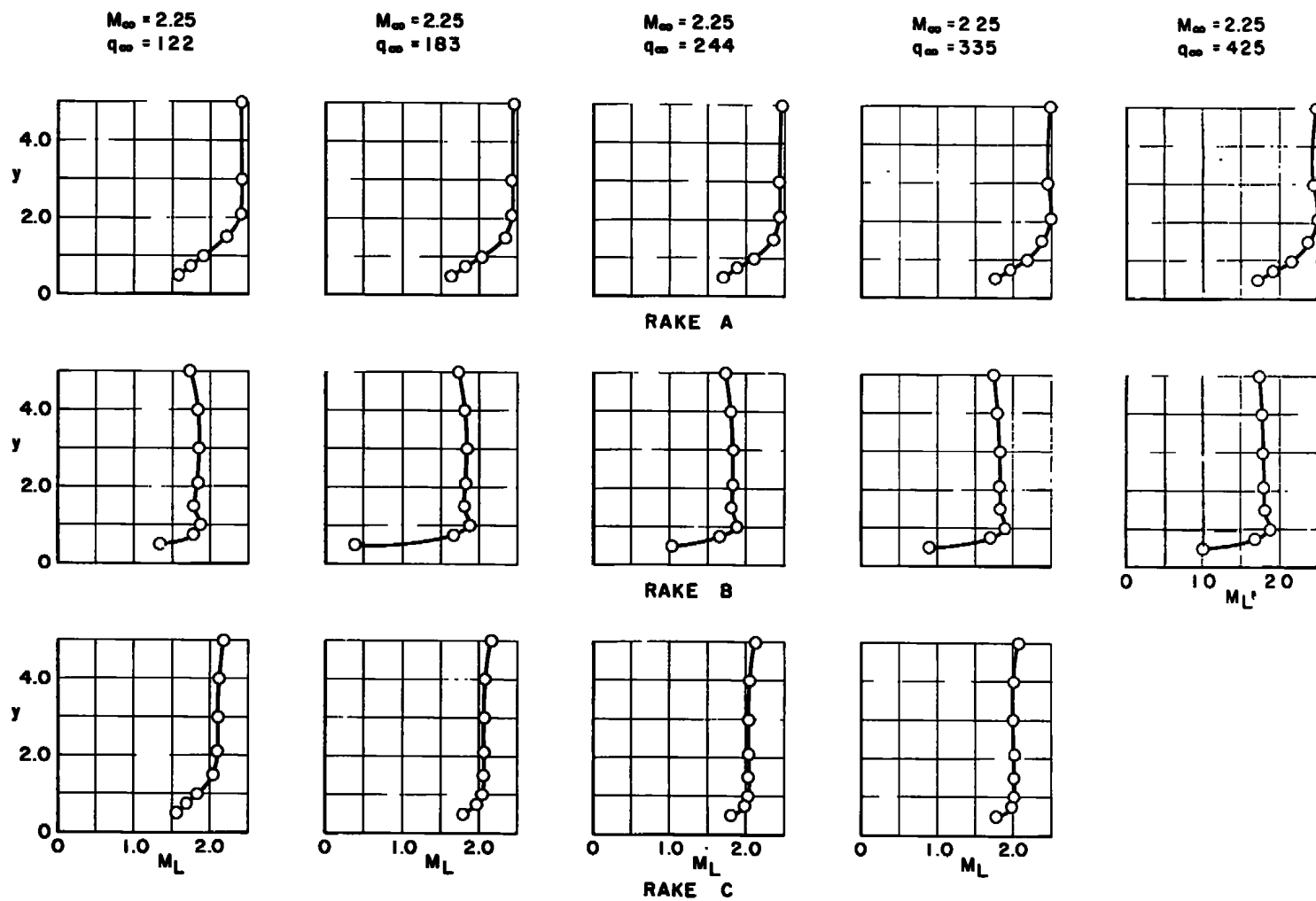


d. Nominal Mach Number 1.70
Fig. 6 Continued



e. Nominal Mach Number 2.00

Fig. 6 Continued



f. Nominal Mach Number 2.25
 Fig. 6 Concluded

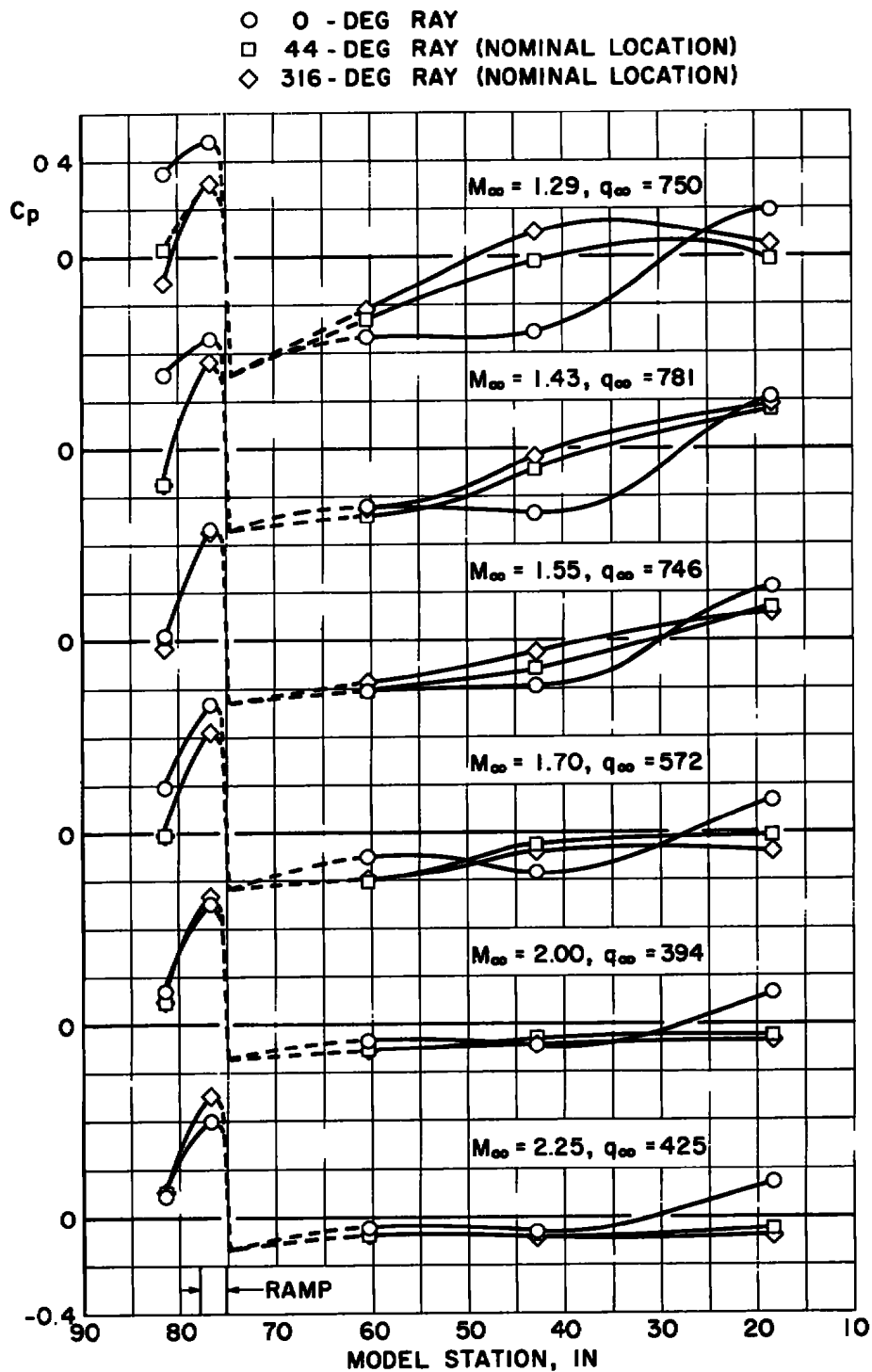


Fig. 7 Variation of Surface Pressure Coefficient with Model Station for $\alpha, \psi = 0$ deg

TABLE I
SCALE FACTORS

Quantity	Ratio of Model to Full Scale
Length	0.500
Dynamic pressure	0.650
Temperature	1.000
Mach number	1.000
Mass	0.08125
Frequency	2.000
Young's modulus	0.650

TABLE II
DISCRETE TEST CONDITIONS FOR PRESSURE SWEEPS

α	ψ	M_∞	M_{LA}	q_∞	q_{LA}	$Re/ft \times 10^{-6}$
Nominal $M_\infty = 1.25$						
-0.03	0	1.21	1.29	168	163	0.82
-0.03	↓	1.24	1.25	356	330	1.70
-0.03		1.25	1.24	554	512	2.63
-0.03		1.29	1.28	750	714	3.52
-4.02	0	1.25	1.27	106	103	0.52
-4.02	↓	1.26	1.31	171	166	0.82
-4.08		1.27	1.33	346	337	1.64
-4.15		1.26	1.37	557	553	2.68
-4.20		1.26	1.38	742	736	3.58
0	-2.99	1.23	1.30	105	104	0.51
↓	-3.01	1.24	1.34	174	173	0.84
	-3.01	1.27	1.32	345	339	1.65
	-2.95	1.27	1.32	561	554	2.68
	-3.03	1.28	1.31	748	730	3.56
Nominal $M_\infty = 1.40$						
0.00	0	1.46	1.42	93	88	0.43
-0.01	↓	1.44	1.39	173	159	0.79
-0.01		1.46	1.47	194	187	0.88
-0.01		1.46	1.47	282	264	1.27
0.00		1.43	1.43	392	367	1.76
-0.01	0	1.44	1.41	175	162	0.81
-0.01	↓	1.45	1.46	347	326	1.63
-0.01		1.43	1.47	578	547	2.70
-0.01		1.43	1.49	781	743	3.63
-4.02	0	1.39	1.39	109	107	0.51
-4.05	↓	1.33	1.30	178	170	0.84
-4.02		1.34	1.33	348	332	1.64
-4.05		1.39	1.49	570	557	2.64
-4.13		1.40	1.51	794	776	3.66
0	-3.99	1.38	1.38	108	107	0.50
↓	-4.01	1.41	1.45	177	173	0.82
	-4.07	1.42	1.48	345	338	1.60
	-3.96	1.42	1.52	563	553	2.60
	-4.00	1.42	1.54	804	790	3.70

TABLE II (Cont'd)

α	δ	M_∞	M_{LA}	q_∞	q_{LA}	$Re/ft \times 10^{-6}$
Nominal $M_\infty = 1.50$						
-0.04	0	1.53	1.48	172	155	0.79
-0.06	↓	1.51	1.59	357	344	1.62
-0.04	↓	1.47	1.53	570	533	2.58
0.01	0	1.49	1.50	110	104	0.50
0.00	↓	1.48	1.50	196	184	0.91
0.00	↓	1.50	1.58	350	332	1.61
0.00	↓	1.54	1.66	565	541	2.58
-0.01	↓	1.55	1.70	746	718	3.40
-4.05	0	1.50	1.48	106	103	0.50
-4.08	↓	1.52	1.52	174	165	0.80
-4.12	↓	1.54	1.57	343	325	1.56
-4.19	↓	1.55	1.63	559	539	2.54
-4.27	↓	1.55	1.67	754	735	3.41
0	-4.01	1.48	1.45	111	103	0.51
↓	-4.04	1.51	1.42	181	150	0.82
	-3.99	1.52	1.30	353	238	1.61
	-4.04	1.52	1.58	556	533	2.55
	-3.92	1.52	1.60	750	725	3.43
Nominal $M_\infty = 1.70$						
0.00	0	1.70	1.67	164	158	0.78
0.00	↓	1.70	1.72	245	238	1.14
0.01	↓	1.70	1.77	375	370	1.65
0.02	↓	1.70	1.79	490	483	2.14
0.04	↓	1.70	1.79	572	564	2.50
-3.92	0	1.70	1.68	164	160	0.79
-4.01	↓	1.70	1.79	369	368	1.66
-3.98	↓	1.70	1.81	490	489	2.16
-4.00	↓	1.70	1.83	574	572	2.50
0	-4.00	1.70	1.70	164	161	0.78
↓	-4.06	1.70	1.76	369	372	1.66
	-4.03	1.70	1.78	493	496	2.17
	-4.06	1.70	1.80	573	578	2.49

TABLE II (Cont'd)

α	ψ	M_∞	M_{L_A}	q_∞	q_{L_A}	$Re/ft \times 10^{-6}$
Nominal $M_\infty = 2.00$						
-0.04	0	2.00	1.98	143	128	0.71
-0.04	↓	2.00	2.03	214	194	1.04
-0.04	↓	2.00	2.04	287	259	1.35
-0.05	↓	2.00	2.08	394	360	1.81
-3.97	0	2.00	1.99	142	133	0.71
-3.99	↓	2.00	2.00	214	202	1.04
-3.97	↓	2.00	2.02	285	272	1.35
-3.98	↓	2.00	2.04	394	376	1.81
0	-4.01	2.00	2.03	141	132	0.70
↓	-4.04	2.00	2.04	213	203	1.01
	-4.04	2.00	2.07	284	272	1.31
	-4.08	2.01	2.09	446	425	1.98
Nominal $M_\infty = 2.25$						
-0.04	0	2.25	2.40	122	114	0.64
-0.03	↓	2.25	2.45	183	172	0.94
-0.02	↓	2.25	2.46	244	230	1.22
-0.03	↓	2.25	2.48	335	311	1.62
-0.02	↓	2.25	2.50	425	390	1.98
-4.00	0	2.25	2.28	123	114	0.63
-4.01	↓	2.25	2.27	183	172	0.93
-4.04	↓	2.25	2.31	244	232	1.21
-4.03	↓	2.25	2.33	335	321	1.60
-4.01	↓	2.25	2.35	426	408	1.97
0	-3.98	2.25	2.31	124	117	0.64
↓	-4.03	2.25	2.36	183	176	0.92
	-4.04	2.25	2.40	245	239	1.20
	-4.08	2.25	2.44	335	329	1.58
	-4.12	2.25	2.46	426	417	1.93
Nominal $M_\infty = 1.70$, Fixed End						
0.00	0	1.70	1.64	164	155	0.80
-0.01	↓	1.70	1.69	247	241	1.17
-0.01	↓	1.70	1.75	370	364	1.68
-0.01	↓	1.70	1.78	491	487	2.18
-0.01	↓	1.70	1.79	573	566	2.51

TABLE II (Concluded)

α	ψ	M_∞	M_{L_A}	q_∞	q_{L_A}	$Re/ft \times 10^{-6}$
Nominal $M_\infty = 2.00$, Fixed End						
0.01	0	2.00	1.96	179	158	0.85
0.00	↓	2.00	1.99	213	192	1.00
0.01		2.00	2.02	286	254	1.31
0.01		2.00	2.07	392	358	1.75
0.01		2.00	2.09	447	408	1.97
-3.99	0	2.00	1.97	178	165	0.86
-4.00	↓	2.00	2.01	215	202	1.02
-4.03		2.00	2.03	286	267	1.33
-4.00		2.01	2.05	390	363	1.77
-4.03		2.02	2.08	476	451	2.13
Nominal $M_\infty = 2.25$, Fixed End						
0.01	0	2.25	2.38	122	113	0.63
0.01	↓	2.25	2.50	183	168	0.92
0.01		2.25	2.48	244	229	1.20
0.01		2.25	2.50	335	310	1.59
0.01		2.25	2.52	426	390	1.94

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13. ABSTRACT A 0.50-scale model of the meteoroid shield portion of the MOL laboratory vehicle was tested in Tunnels 16T and 16S of the Propulsion Wind Tunnel Facility. The model consisted of a sting-supported hollow duct assembly about which the dynamically scaled meteoroid shield skin and various protuberances were mounted. The test objective was to determine if the shield was free of destructive flutter in the flight dynamic pressure environment. Principal shield data included measurements of strain, displacement, temperature, noise level, surface pressure, and boundary-layer profile. Data were recorded at nominal Mach numbers from 1.25 to 1.50 in Tunnel 16T and from 1.70 to 2.25 in Tunnel 16S. Dynamic pressure was varied from tunnel minimums to levels that exceeded the scaled flight value. No indications of flutter were observed. Each transmittal of this document outside the Department of Defense must have prior approval of SAMSO (SMSDI-STINFO), AF Unit Post Office, Los Angeles, California 90045.			

14.

KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

ROLE

WT

orbital spacecraft

manned spacecraft

meteoroids

flutter tests

aerodynamic vibration

1. Space vehicle -- Shielding
 2. " " -- Flutter
 3. Shields -- "

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